§3. Statistical Analysis of Density Fluctuation in SOL/Divertor Plasmas of the LHD with Super-SINET

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In the edge plasma of several types of fusion devices, experimental measurements have shown a spiky rather than random behavior of plasma fluctuations[1-5]. The fluctuations are self-similar, the self-similarity parameter varies little from one device to another. Discrepancies with classic heat diffusive scaling leaded to the searching of evidence of ballistic transport in fusion devices, suggesting the universality of self-similarity properties in edge of magnetically confined plasmas.

To describe long-term dynamic behavior of a stochastic system, the suitable statistical description is needed. Traditional methods like spectral ones have shown deviation from simple self-similarity (monofractality). Kolmogorov (1962) [6] formulated hypothesis invoking some statistical independence in the cascading process, which led to the log-normal model for the rate of dissipation of turbulent kinetic energy. To describe distinguish between absolute and weighted curdling of stochastic physical system, the statistical description by multifractal formalism was proposed by Mandelbrot [7]. The multifractal formalism relies on the fact that the highly nonuniform probability distribution arises from the nonuniformity of the system possessing rich scaling properties and self-similarity.

Plasma density fluctuations observed with divertor probes in LHD [8] were analyzed in terms of multifractal formalism revisited with wavelets. When $I(t)$ is the time evolution of ion saturation current, a trajectory in a q-dimensional space can be reconstructed with embedding method. Then, we can obtain a series of q-dimensional vectors $\vec{r}_i$, representing the phase portrait of the dynamical system:

$$\vec{r}_i = \{I[t_i], I[t_i+\tau], \ldots, I[t_i+(q-1)\tau]\} \quad i = 1,2,3,\ldots,m \qquad (1)$$

where τ is appropriate delay time.
The multifractality can be described by following formula:

$$M(r) = \left\langle \left|\vec{r}_i - \vec{r}_j\right|^q \right\rangle \approx r^{\zeta(q)}, \qquad (2)$$

$$\zeta(q) = qH - \lambda^2 q^2 \quad . \qquad (3)$$

λ^2 means multifractality parameter. When $\lambda^2 = 0$, the system is mono-fractal,

Figure 1(a) and (b) show the typical time evolution of ion saturation currents measured at different positions. By using Eps. (1) and (2), we can obtain $\zeta(q)$ and λ^2 is determined by Eq. (3). Apparently, both λ^2's are finite value, which means that the fluctuation in the edge plasma of LHD can be characterized by multifractality. Multifractality factor defined in multiplicative cascade model, could be relevant parameter to characterize the edge plasma turbulence. To find whether the parameters of multifractality observed in this analysis, have a more universal validity, it would be interesting to extend multifractal analysis to a broader set of turbulent data from edge plasmas.

We also investigated bursts waiting-time statistics to examine the SOC model. From data of Figs. 1(a) and (b), it is found that the waiting time statistics is not a Poisson process.

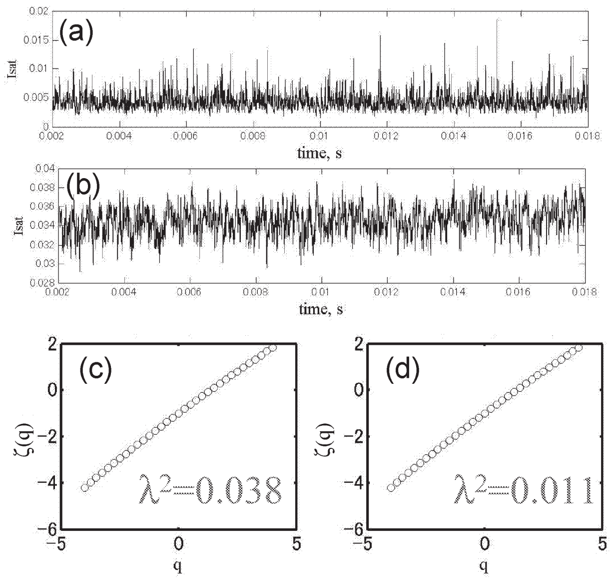

Fig. 1 (a),(b):typical time evolution of ion saturation currents measured with divertor probes in LHD, (c),(d): determination of multifractal parameter corresponding to (a) and (b) respectively.

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